Code

```
%% Clear workspace and configure display
close all;
clearvars;
clc;

% Configure Bode plot options
opts = bodeoptions('cstprefs');
opts.Title.Interpreter = 'latex';
opts.XLabel.Interpreter = 'latex';
opts.YLabel.Interpreter = 'latex';
opts.Title.FontSize = 12;
opts.XLabel.FontSize = 12;
opts.YLabel.FontSize = 12;
opts.XLabel.String = 'Frequency (Hz)';
opts.Title.String = 'Bode Diagram';
opts.FreqUnits = 'Hz';
opts.Grid = 'on';

```

Nominal parameters of the R2P2 converter from Table II.

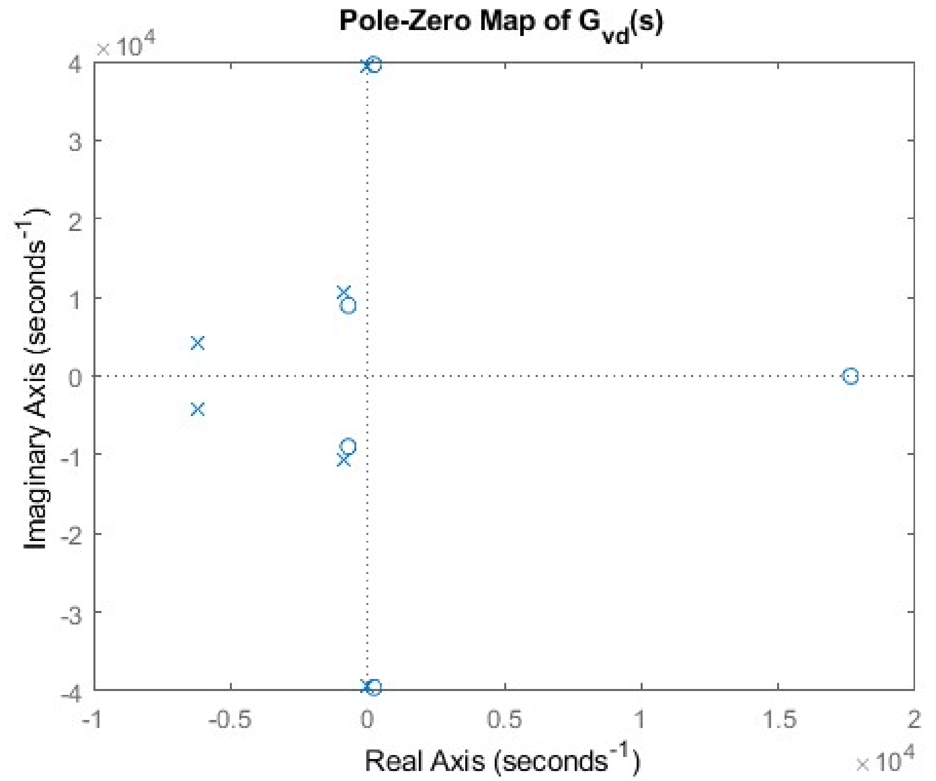
```
%% Nominal parameters of the R2P2 converter
L1 = 66e-6;    % Inductor L1 [H]
L2 = 1350e-6; % Inductor L2 [H]
L3 = 1120e-6; % Inductor L3 [H]
C1 = 10e-6;    % Capacitor C1 [F]
C2 = 10e-6;    % Capacitor C2 [F]
C3 = 10e-6;    % Capacitor C3 [F]
D = 0.633;     % Duty cycle
R = 7.07;      % Load resistance [Ohm]
E = 120;       % Input voltage [V]
fs = 50e3;     % Switching frequency [Hz]

```

State-space small signal model from equation (34)

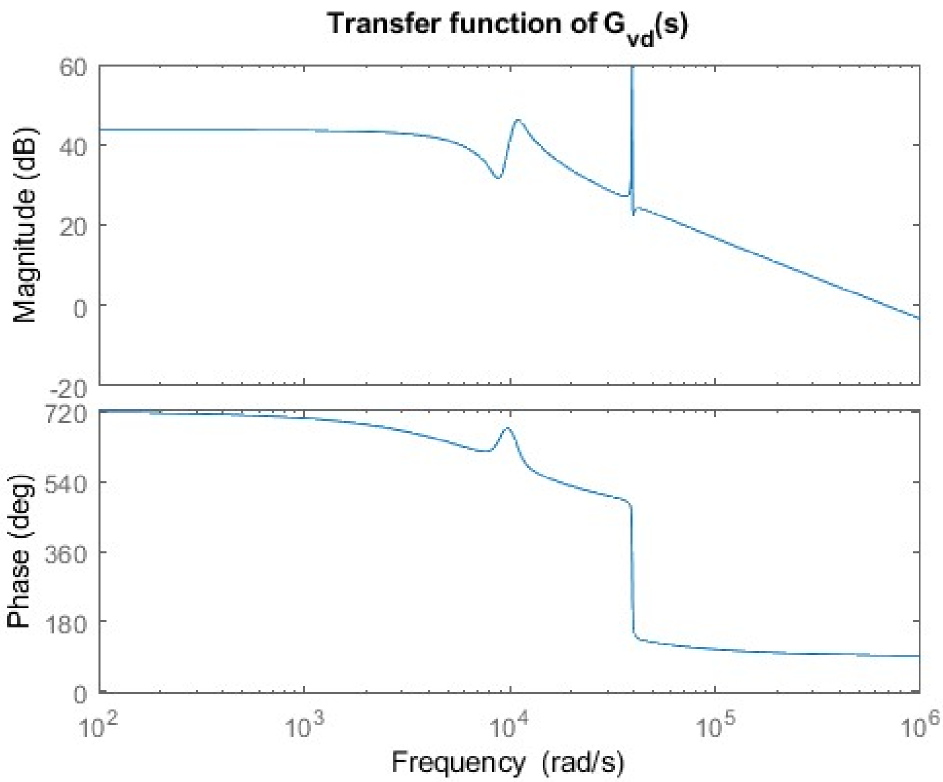
```
%% State-space matrices
A = [0   0   0 -1/L1   0   0;
     0   0   0  D/L2 -1/L2 -1/L2;
     0   0   0   0   D/L3 -(1-D)/L3;
     1/C1 -D/C1  0   0   0   0;
     0  1/C2 -D/C2  0   0   0;
     0  1/C3 (1-D)/C3  0   0 -1/(R*C3)];

B1 = [0;
      E/L2;
      (E*D)/L3;
      -(E*(D^3))/(C1*R);
      -(E*(D^2))/(C2*R);
      -(E*(D^2))/(C3*R)];

B2 = [1/L1; 0; 0; 0; 0; 0];

C6 = [0 0 0 0 0 1]; % Output selection (voltage at C3)

```

Transfer function from duty cycle to output voltage from equation (35)

```
%% Transfer function from duty cycle to output voltage
[num, den] = ss2tf(A, B1, C6, 0);
Gvd = tf(num, den);

% Plot pole-zero map
figure;
pzmap(Gvd);
title('Pole-Zero Map of G_{vd}(s)');

figure
bode(Gvd)
title('Transfer function of G_{vd}(s)');
```



Pole-Zero Map of $G_{vd}(s)$
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
$\times 10^4$
4
3
2
1
0
-1
-2
-3
-4
-1
-0.5
0
0.5
1
1.5
2



Transfer function of $G_{vd}(s)$
Magnitude (dB)
60
40
20
0
-20
Phase (deg)
720
540
360
180
0
10^2
10^3
10^4
10^5
10^6
Frequency (rad/s)

Fig. 8: Mapping of poles and zeros of the transfer function

```
59      %% Controller parameters
60      V_out = 48;      % Desired output voltage [V]
61      F_sw = 50e3;     % Switching frequency [Hz]
62      Vp = 3;          % Peak voltage of the modulator
63      Km = 1 / Vp;     % Modulation gain
64      V_ref = 3;       % Reference voltage [V]
65      H = V_ref / V_out; % Sensor gain
66
67      % Controller design parameters
68      fc = 1750;        % Target crossover frequency [Hz]
69      wc = 2 * pi * fc; % Target crossover angular frequency [rad/s]
70      wz = 2 * pi * 500;    % Zero frequency [rad/s]
71      wp = 2 * pi * 5000;   % Pole frequency [rad/s]
72
73      % Open-loop transfer function
74      L_open = Gvd * Km * H;
75
76      % Compute gain at crossover frequency
77      s = tf('s');
78      [mag, ~] = bode(L_open, wc);
79
80      % Lead-lag compensator
81      G2 = ((s / wz + 1)^2) / (s * (s / wp + 1)^2);
82      [mag2, ~] = bode(G2, wc);
83      K = wc * (1 + (wc / wp)^2) / (mag * (1 + (wc / wz)^2));
```

Control equation (36) from code line 83:

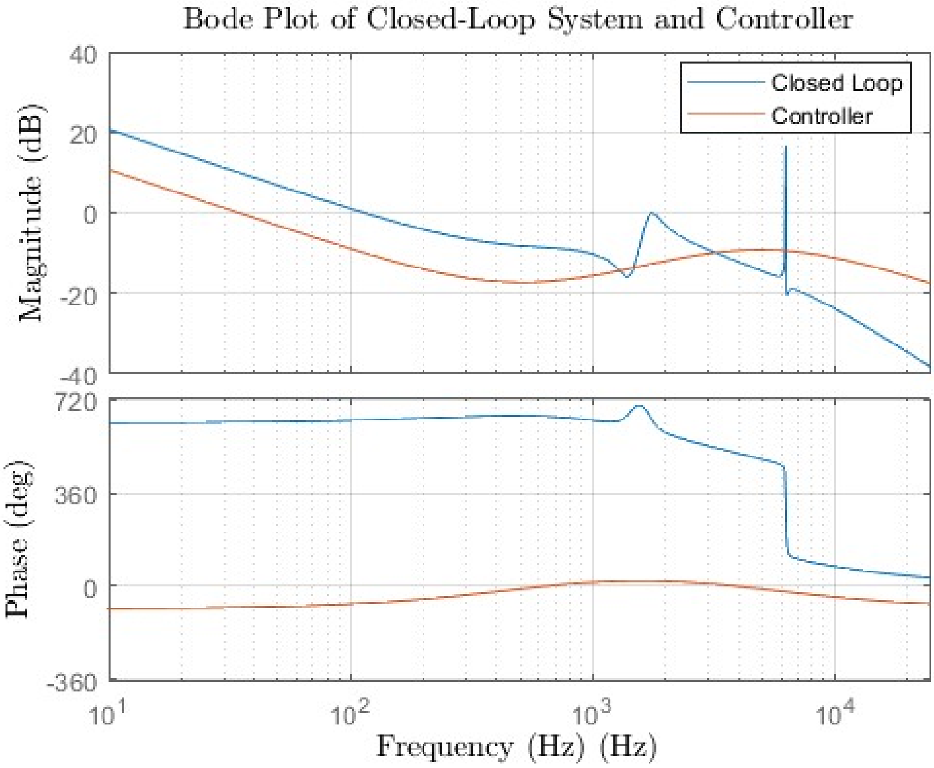
$$K(s) = \frac{K\left[\frac{s}{w_z} + 1\right]^2}{s\left[\frac{s}{w_p} + 1\right]^2}$$

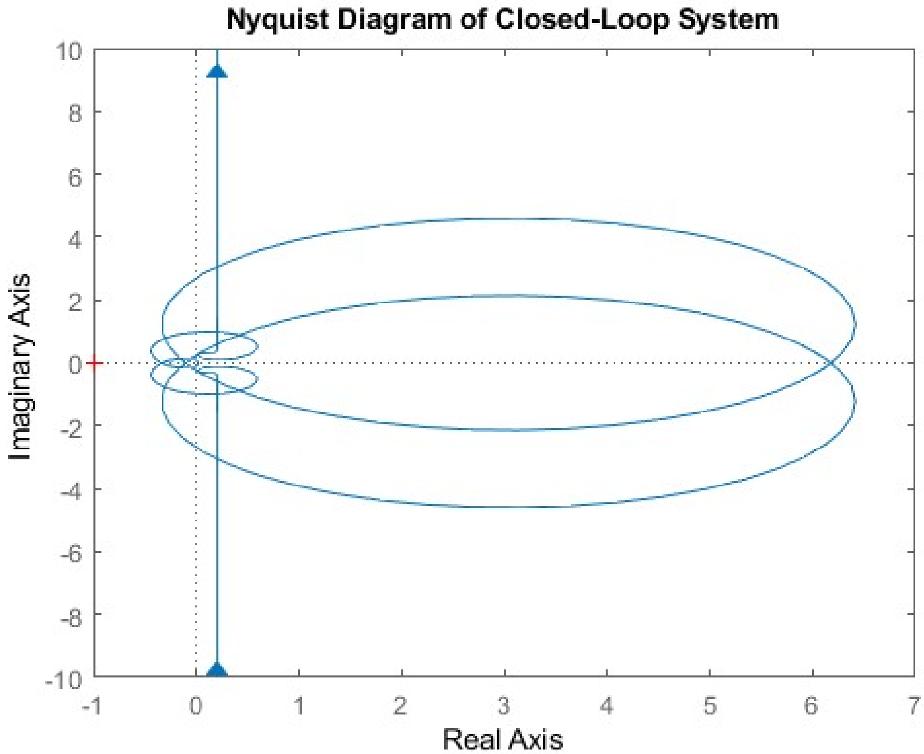
Component values from controller parameters in Table IV.

```
%% Component values for controller implementation
R1x=10000
C3x=1/R1x*(1/wz-1/wp)
C1x=wz/(wp*R1x*K)
C2x=1/(R1x*K)-C1x
R2x=(C1x+C2x)/(C1x*C2x*wp)
R3x=1/(C3x*wz)-R1x

% Controller transfer function
G=(s*R2x*C2x+1)*(s*C3x*(R1x+R3x)+1)/((s*R1x*(C1x+C2x)*(1+s*R2x*(C1x*C2x)/(C1x+C2x))*(s*R3x*C3x+1)));

Hc = G;

% Extract zeros and poles in Hz
[numHc, denHc] = tfdata(Hc, 'v');
[zHc, pHc, ~] = tf2zp(numHc, denHc);
zHc_hz = zHc / (2 * pi);
pHc_hz = pHc / (2 * pi);

% Closed-loop system
L_cl = minreal(G * L_open);
```

```
%% Plot results
figure;
bode(L_cl, opts);
hold on;
bode(G, opts);
title('Bode Plot of Closed-Loop System and Controller');

figure;
nyquist(L_cl);
title('Nyquist Diagram of Closed-Loop System');
```

Results from Fig. 10 and Fig. 11.:


Bode Plot of Closed-Loop System and Controller
Closed Loop
Controller
Magnitude (dB)
40
20
0
-20
-40
Phase (deg)
720
360
0
-360
10^1
10^2
10^3
10^4
Frequency (Hz) (Hz)


Nyquist Diagram of Closed-Loop System
Imaginary Axis
10
8
6
4
2
0
-2
-4
-6
-8
-10
-1
0
1
2
3
4
5
6
7
Real Axis